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RESEARCH ARTICLE

Development of a prosthetic hand regarding complex motion and controllability

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Abstract

In this paper, the critical issues of currently available upper limb prostheses are highlighted; also possibilities of usability improvement are propounded.Although contemporary prosthetic hand constructions are extremely complex and allow numerous movements, they do not give opportunities for many people, because of the difficulties in proper use and the high costs.Based on the aformentioned aspects, the development of such a construction has been started, that hopefully provide solutions both in the ease of use and in cost reduction.After giving a brief overview of upper limb prostheses and detailing the major difficulties, the current state of the device under development is presented, as well as the results of analysesand the direction of future research.

Keywords

biomechatronics · prosthetic hand · development

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1 Introduction

The topic of upper limb prostheses is so diversified, that notwithstanding the amount of literature available, the research in this area is justified. The difficulties accompanying the everyday use of contemporary constructions inspired the work started at the Budapest University of Technology and Economics, to design a device with low manufacturing costs that provides the ease of controllability and at the same time is able to accomplish complex movements.

Construction criteria had been established after detailed overview of relevant anatomy and physiology, as well as medical cases, and survey of the characteristics of currently available upper limb prostheses, so that the first CAD model could be made [1].

The movement of multiple models were analysed to maximize usability. A number of images were taken and processed of the movements of a real hand and an experimental design. The comparison of these results and that of the mathematical model, adequate finger movement is warranted. Further refinement of the CAD model was also done, to satisfy the criteria of traction element motion.

The actuator and the control system is currently under development, hopefully the complete documentation for manufacturing will be ready soon.

2 General overview

There is a long history in the fabrication of various devices intended to compensate for the loss of limbs, however their development sped up only during the last couple of decades, so that there could be significant changes both in construction and function. In order to obtain a comprehensive view, functional categorization of artificial limbs and relevant historical milestones will be discussed as a unit. Upper limb prostheses can be divided into the following four groups [2]:

- cosmetic arm
- utility arm
- functional arm
- powered arm

2.1 Cosmetics and utility arms

The sole purpose of cosmetic prostheses is to reproduce the look of original limb, they do no have any functionality. That is why cosmetic prostheses were the first to appear, they are widely used for thousands of years. Since it has no such usability as a real limb, nowadays it is exceeded by more advanced types, and it is mostly used for minor replacements only, and the low price gives some reason for its continued existence.

Utility arms characteristically look different from real limbs, however have minimal functionality to execute specific tasks. The general use of utility arms is also not so prevalent today, nevertheless there are special purposes for which they are extremely useful (e.g. bicycling, fishing).

Fig. 1. Cosmetic arm (left) and utility arm (right)

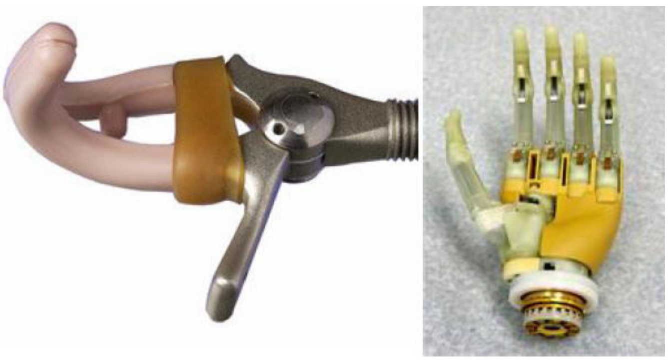

Fig. 2. Functional arm (left) and powered arm (right)

2.2 Functional and powered arms

Functional arms have no additional drives, they are only “human-powered”, and their construction is relatively simple, too. It would be possible to manufacture more complex functional arms, however it is rather pointless, because the user would not be able to handle it properly. That is why functional arms are mostly hooks that can be opened and closed,sometimes with a cover imitating the real arm.

Arms that can be controlled and are powered by external energy sources are the results of cooperation between engineers and medical professionals, during the last couple of decades. Their complexity in connection with the multitude of movements ranges in a wide scale. Powered arms have the most potential however their use raises numerous problems.

3 Problems with current models

As it was mentioned in the introduction, there are two problems concerning contemporary high-tech hand prostheses [3]. First, the price is extremely high, that does not need further explanation. The other problem is the difficulty and complexity to control the device.

Control is implemented almost exclusively by myoelectric signals, having several difficulties. Signals are obtained from electrodes attached to the skin, whose number varies between 70 and 200. Such a great number of electrodes poses not just the question of comfort,but the real problem is that completely different muscle groups have to be used to move the prosthesis (to provide the necessary myoelectric signals), than those used by a biological hand.

This task of adaptation is extremely difficult, in some cases utterly impossible, after the trauma of amputation or for elderly people. That is why, that high-tech artificial limbs (available only for relatively few people), are even more restricted.

3.1 Possible solution

It is clear that one possibility of the solution is the development of the human-machine interface. The interface using EMG signals has a long tradition [4], however – based on the former – it is evident, that in fact it is a forced solution; the development and application of an interface closer to natural would be a much more efficient solution [5].

The complete replacement of human-machine interface was accomplished only in the most advanced artificial limbs (EEG-controlled prostheses) [6, 7]. In case of the EEG controlled prostheses, the intelligent pattern recognition plays an essential role – the typical EEG forms can be differentiated by the use of fuzzy systems [8–11]. It is clear, that in case of EMG and EEG/ECoG controlled prosthetic arms, the development of new control algorithms can lead to useful results.

These results are not yet feasible in the current task, because of the above mentioned goal of low manufacturing costs, so the solution is the simplicity of the structure. The development of a new, improved human-machine interface exceeds the scope of the task, so by all means, a different solution shall be chosen. The objective is not to be borne in mind; the device under development is meant to help users as widely as possible. Since the problems of controllability arise from the complex system – even though it may seem a step back, compared to high-end devices – simplification of the control system and the mechanical design is the appropriate solution. These also mean a reduction in production and development costs, so in this case that is the correct direction of development.

Consequently the development goals are a trade-off between the most complex motions and the simplest construction. The planned construction has five individually bendable fingers, the

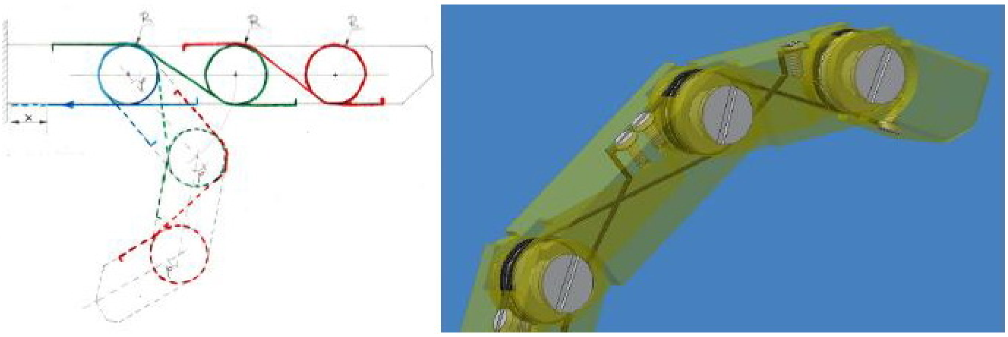

Fig. 3. One of the long fingers in the experimental device

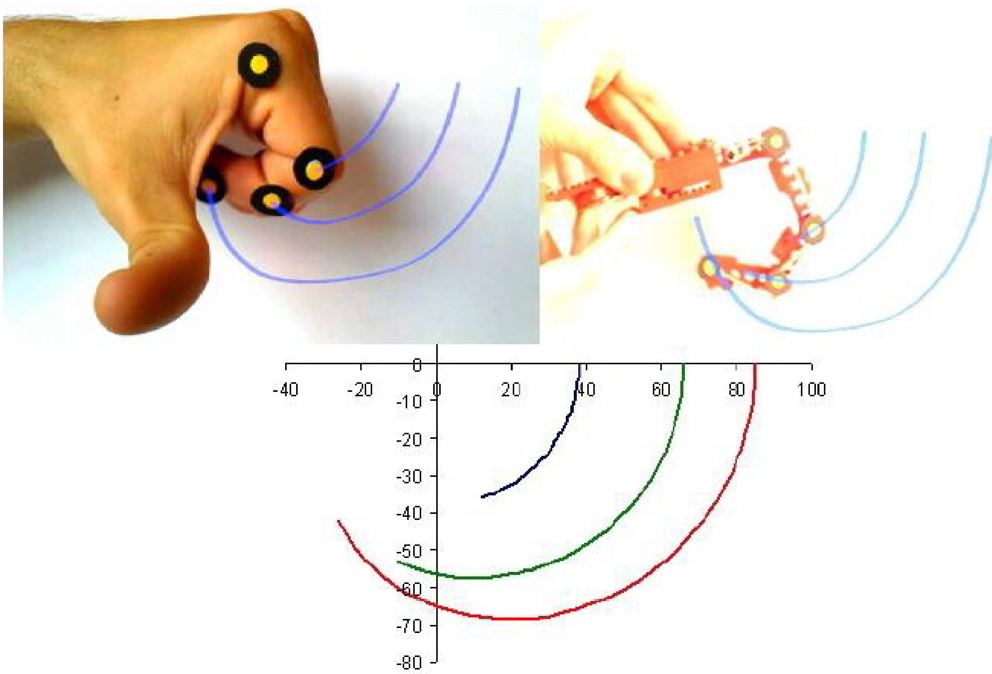

Fig. 4. Results of movement analysis.

thumb provides opposition, and the fingers can be spread and closed. In directions where no force is necessary (e.g. straightening of fingers), passive return could be used,further simplifying construction.

Such a design can use less actuators compared to available high-tech models, in the same time it allows the most common everyday hand movements. Simple construction and controllability are provided, and the original objective of helping its user the highest extent is also fulfilled.

4 The experimental device

The device under development uses traction element motion, the structure is widelyused in flexible grippers [12, 13], it is a good choice fro hand prostheses. Fig. 3. shows the movement of fingers of the experimental device.

Because of the attachment of wires individual joints have the same angular range. To verify the movement of the experimental device, a comparison was made, the results of which are shown in Fig. 4 [14].

As the results proved it, the trajectories are sufficiently similar, so tha experimental device works appropriately. After answering further question and problems – especially the choice of material for individual parts – the complete device can be created.

5 Tasks for the near future

Two major tasks are the manufacturing of the device, then the design and implementation of the control system. Manufacturing does not seem to be a problem, the completion of the technical documentation is well under way. However, the design and implementation of the control system have both theoretical and practical challanges.

The base of operation is position control, complemented with force-feedback, thus total controllability can be achieved. To analyse the possibilities in force-feedback control, a gripper mechanism equipped with load cells, developed at the Budapest University of Technology and Economics [15] is examined from control engineering aspects.

Most robotic arms use some mean of force-feedback, that is absolutely reasonable [16–18] because the information from the sense of touch is highly important in the case of the real hand also. Force-feedback is necessary, because multi-loop control with visual feedback towards the user and position control with inner feedback loops are not sufficient for fine movement [14].

The goal is to provide force-feedback both in the mechanism's side and rather for the user. The latter is still one of the biggest challenges in the development of upper limb prostheses. The topic of making a kind of force feedback available directly to the use is a topic that holds extremely useful results, and extraordinary change in the usability of prosthetic arms.

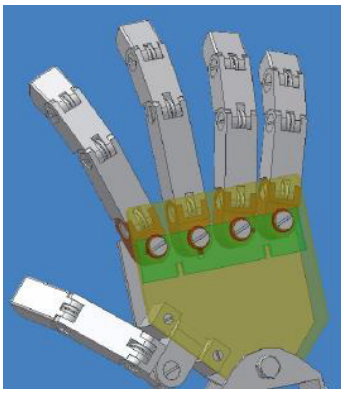

Fig. 5. CAD model of the complete device.

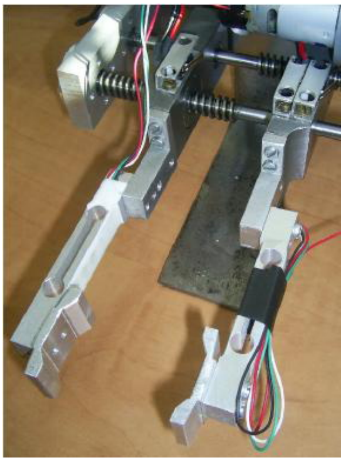

Fig. 6. Robot gripper with force-feedback [15].

6 Conclusion

In spite of the various areas of problems and tasks, design and analysis proceeds continuously. The manufacturing, based on the recent model development is soon to commence, so that the mechanism will be available for measurements and experiments.

The control system is being developed simultaneously, the results of the currently run force-feedback analysis will provide useful aspects to extend position control and to reach the goals.

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